0038-075X/08/17306-408–416
Soil Science

June 2008
Vol. 173, No. 6
Printed in U.S.A.

MONITORING CHANGES IN THE CHEMICAL PROPERTIES OF AN OXISOL UNDER LONG-TERM NO-TILLAGE MANAGEMENT IN SUBTROPICAL BRAZIL

M. Fátima Guimarães[1], Inês C. B. Fonseca[1], Michel Brossard[2], Cibele M. R. Portella[1], Osmar R. Brito[1], and Jerry C. Ritchie[3]

In tropical areas, soil chemical properties are most often studied in relationship to the type of tillage system. This article presents data of the long-term effects of no-tillage (NT) management systems on the soil chemical properties of an oxisol in subtropical Brazil. The study area was on a commercial farm where NT systems had been adopted in 1978. Soil samples were collected annually from 1983 to 1994 after winter crop harvest in 16 fields and at depths of 0.0 to 0.1 m and 0.1 to 0.2 m. Organic C, exchangeable calcium, magnesium, potassium, extractable phosphate, and pH were measured. Soils were grouped by a multivariate statistical agglomerative hierarchical method into five classes (I–V) based on statistical similarity to assess annual changes in soil chemical properties. This study shows that it is possible to maintain good soil chemical properties under operational NT systems in these subtropical conditions. This study also demonstrated the importance of sequence of crops for maintaining acceptable levels of soil organic matter and good soil chemical properties. (Soil Science 2008;173:408–416)

Key words: No-tillage, soil management, chemical properties, soil organic carbon, clay soils, oxisol.

THE challenge for agriculture in subtropical and tropical areas is to maintain the soil productivity for food and fiber production (Stocking, 2003). Many soil management systems have been studied for controlling erosion, improving and maintaining soil fertility, and reducing production costs. Among these systems, no-tillage (NT) systems reduce machinery use, fuel, and labor in agriculture as well as provide good conditions for initial emergence and development of plants, improving erosion control, increasing soil organic matter, and reducing soil nutrient losses (Blevins et al., 1977; Cannel and Finney, 1973). No-tillage systems were introduced in southern Brazil in the 1970s as a management alternative to control soil erosion. By 2003, NT systems in Brazil were used on approximately 22 Mha, whereas conventional tillage (CT) systems were used on approximately 52 Mha.

In the state of Paraná, Brazil, the first NT research was undertaken by the Instituto Agronômico do Paraná in 1971 on oxisol soils developed from sandstone and basalt, which are the dominant soils in the cultivated areas of this region. These studies focused on the changes in chemical (Muzilli, 1983; Oliveira and Pavan, 1996; Sidiras and Pavan, 1985) and physical (Castro Filho et al., 2002; Castro Filho et al., 1998; Roth et al., 1991) properties of the soil. Castro Filho et al. (1998) observed structural homogeneity and improved stability of soil aggregates when CT was eliminated, resulting in greater water infiltration and storage. The use of fertilizers in NT systems without incorporation improved aggregation and increases nutrient availability in the surface layers (CFS, 1994).

[1]Universidade Estadual de Londrina, CCA, Departamento de Agronomia, CP 6001, 86051-990 Londrina-PR, Brazil. Prof. Guimarães is corresponding author. E-mail: mfatima@uel.br

[2]IRD, US VALPÉDO, Montpellier, France.

[3]USDA, ARS, Hydrology and Remote Sensing Laboratory, Beltsville, MD.

Received July 8, 2007; accepted Mar. 3, 2008.

DOI: 10.1097/SS.0b013e31817739fb

Carbon (C), nitrogen (N), phosphorus (P), and exchangeable cations are, in general, more abundant in the surface layers under NT systems than in CT systems (Bayer et al., 2000; Ernani et al., 2002; Leite et al., 2004; Mascarenhas et al., 1978; Muzilli, 1985; Phillips et al., 1980; Silveira et al, 2000). However, research is still needed to evaluate the effects of the NT on soil chemical properties over a period of years for tropical and subtropical areas. Thus, the objective of this study was to measure soil chemical properties of a long-term NT management system under commercial crop production in the subtropical area. Traditionally, data are obtained only at plot scale experiments, and not on long-term time scales. In this study, a data set from a commercial farm was used. The approach was to determine the possible variation of some soil chemical properties using the routine soil analysis at field scale. The commercial farm used in this study had been using NT systems since 1978. This study presents the results from measurements of surface soil concentrations of C and chemical properties from 1983 to 1994.

MATERIALS AND METHODS

Study Area

The selection of the study area was a farm that has more than 15 years of NT management on intensive production fields located on the same soil type in the same watershed, where routine soil analysis was conducted by the same laboratory and methods. The study area is located in the northern part Paraná State (22°57′S, 51°11′W, elevation 600-630 m), Brazil. The soil is classified as Dystroferric Red Latosol (EMBRAPA, 1999), Rhodic Ferralsol, Typic Haplustox with clay contents varying from 710 to 800 g kg^{-1} for soils typical of the area (Table 1). The natural soil structure shows little or no distinct horizonation with moderate macrostructure and typically has a strong microstructure (small stable rounded aggregates that form a network of pores) that allows a strong infiltration rate. The slope of the study area varied from 4% to 6%. The climate is subtropical, humid, with average maximum/minimum temperatures of 22/18 °C. Average annual precipitation is 1850 mm. The region is subjected to occasional frosts between April and October.

The study area on a commercial farm has been using NT management system since 1978. This study focused on the 1983 to 1994 period. Before beginning the NT system, the area was managed using CT systems. The study area was 209.5 ha divided into 16 fields (Fig. 1). Soil properties of the area were determined for the 16 fields and an adjacent forest area.

Crops of wheat (*Triticum aestivum* L.), corn (*Zea mays* L.), soybean (*Glycine max* (L.) Merr.), oats (*Avena sativa* L.), rye (*Secale cereale* L.), triticale (*Triticale hexaploide* Lart.), and canola (*Brassica* species) were grown during the study period (Table 2). They were fertilized according to specific recommendations for each crop. Lime was applied at 1030 kg ha^{-1} of dolomite limestone in the beginning of 1984 and at 1906 kg ha^{-1} in 1990 (Table 2). In 1985, the oat crop was used as green manure. The mean yields for soybean, wheat, and corn were 3022, 2975, and 6475 kg ha^{-1}, respectively, during the study period. These yields were considered high for soybean and wheat but average for corn.

Soil Sampling and Chemical Analysis

Composite soil samples from each field were collected each year (except in 1989) at two depths (0.0-0.1 and 0.1-0.2 m) from 1983 to 1994. At least 10 random soil samples from each field were mixed to form each composite sample for that field. Sampling was performed in August

TABLE 1

Soil chemical and physical properties of typical soils in the study area

Location	Depth, m	Bulk density, g cm^{-3}	Clay, g kg^{-1}	OC, g kg^{-1}	Total nitrogen g kg^{-1}	C/N ratio	pH
Field 9	0-0.25	1.35	710	20.4	1.38	19.9	5.4
	0.25-0.50	1.21	770	9.7	0.59	19.9	5.7
	>0.50	1.09	780	15.7	0.83	20.1	5.7
Field 7	0-0.25	1.31	730	21.1	1.38	20.0	5.5
	0.25-0.50	1.17	780	6.9	0.41	19.8	5.9
	>0.50	1.04	800	10.8	0.56	20.1	5.6
Forest	0-0.25	1.04	710	23.1	1.20	20.0	5.4
	0.25-0.50	1.03	770	23.7	1.22	20.0	5.4
	>0.50	1.03	790	13.3	0.70	20.0	4.4

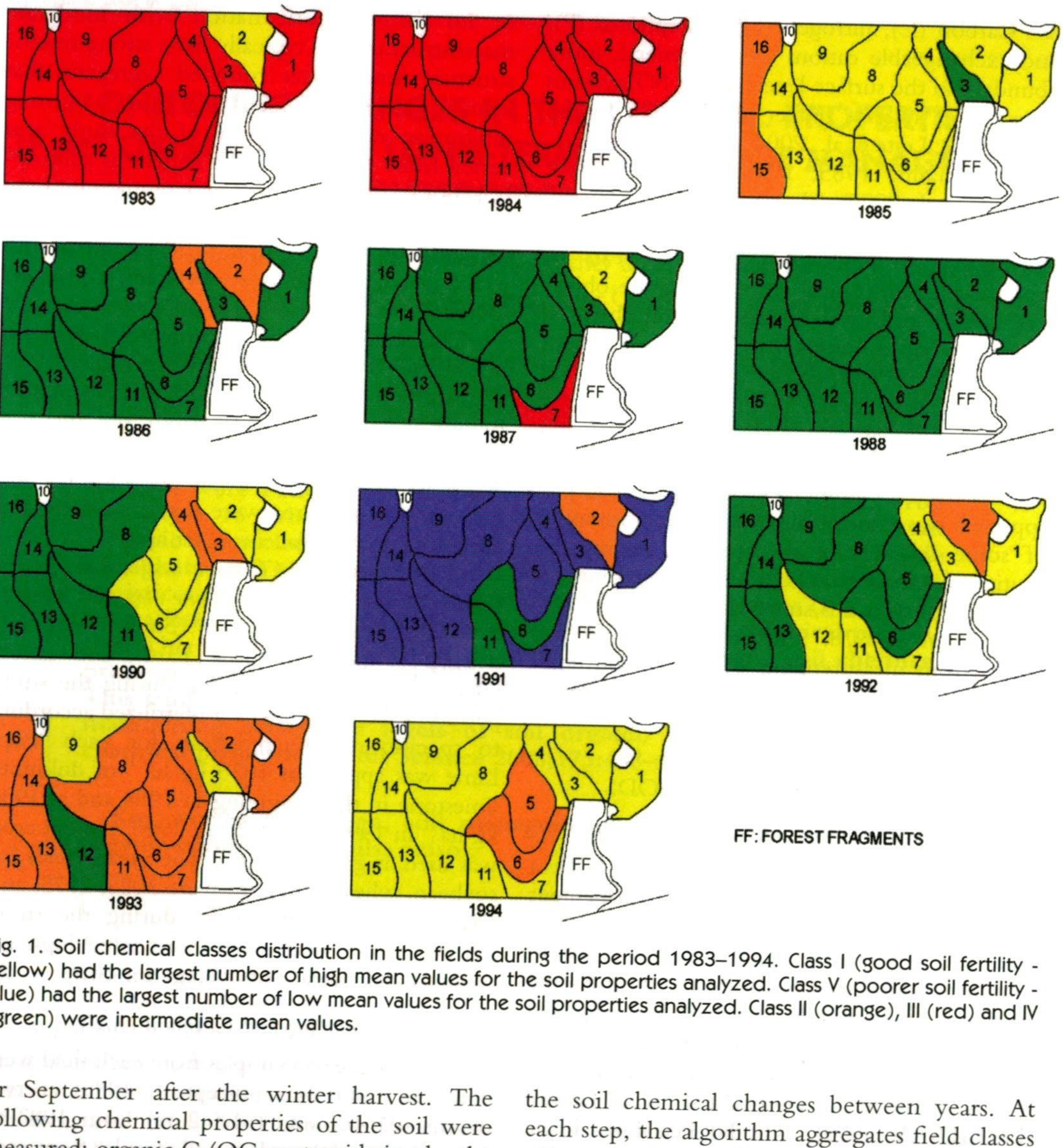

Fig. 1. Soil chemical classes distribution in the fields during the period 1983–1994. Class I (good soil fertility - yellow) had the largest number of high mean values for the soil properties analyzed. Class V (poorer soil fertility - blue) had the largest number of low mean values for the soil properties analyzed. Class II (orange), III (red) and IV (green) were intermediate mean values.

or September after the winter harvest. The following chemical properties of the soil were measured: organic C (OC, wet oxidation by the Walkley and Black method), pH (0.01 *M* $CaCl_2$), calcium and magnesium (Ca and Mg extracted by KCl 1 *M*), extractable potassium (K), and P (Mehlich-1 extractor). Methods and analytical procedures used are described in EMBRAPA (1997).

Statistical Analysis

The experimental design included each field and year combination being characterized by 6 soil properties (OC, pH, P, Ca, Mg, and K) at two soil depths. Multivariate statistical agglomerative hierarchical method (SPAD 3.5, CISIA-CERESTA, 1998) was used to classify the fields into five similar classes for visualizing the soil chemical changes between years. At each step, the algorithm aggregates field classes to create a new class with a minimum dispersion in relation to all classes that can be formed (Ward method).

Class I had the largest number of high mean values for the soil properties. Class V had the largest number of low mean values for the soil properties. Classes II, III, and IV had intermediate mean values for the soil properties.

The means and 95% confidence intervals were calculated for each soil property of the five classes. Class comparisons by soil property and depth were carried out by analyses of variance and mean comparison tests. Tukey test at 0.05 level of probability was used to determine significant differences between the properties. When significant changes were detected

TABLE 2

Cropping sequences in the study area during the study period

		Crop per yr											
Field	Area, ha	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	91/92	92/93	93/94
1	17.06	W/S	W/S	R/S	(O)/C	O/S	W/C	O/S	S/C†	S/S	O/S	TR/C	S/S
2	13.46	W/S	W/S	R/S	(O)/C	O/S	W/C	O/S	S/C†	S/S	O/S	TR/C	S/S
3	6.32	W/S	W/S	W/S	(O)/C	O/S	W/C	O/S	S/C†	S/S	O/S	TR/C	S/S
4	7.87	W/S	W/S	W/S	(O)/C	O/S	W/C	O/S	S/C†	S/S	O/S	TR/C	S/S
5	16.5	W/S	W/S	W/S†	R/C	O/S	W/C	O/S	S/C†	S/S	O/S	TR/C	O/S
6	17.69	W/S	W/S	W/S†	(O)+R/S+C	O/S	W/C	O/S	S/C†	S/S	O/S	TR/C	O/S
7	7.91	W/S	W/S	W/C+S†	(O)/C	O/S	W/C	O/S	S/C†	S/S	O/S	TR/C	O/S
8	27.54	W/S	W/S	W/S†	R/S	W/C	O/S	S/C	O/S†	S/S	O/C	C/S	W/C
9	19.05	W/S	W/S	W/S†	R/S	W/C	O/S	S/C	O/S†	S/S	O/C	C/S	CA+W/C
11	8.86	W/S	W/S	W/S†	(O)/C	O/S	W/C+S	O/S	S/C†	S/S	O/S	TR/C+S	O/S
12	17.16	W/S	W/S	W/S†	O/C	W/C+S	W+O/S	O/S	S/C†	S/S	O/S	W/S	W+O/S
13/14	22.12	W/S	W/S	W/S	O/C	W/C	O/S	S/S+C	O/S†	S/S	O/C	O/S+C	CA+W+O/C
15/16	26.74	W/S	W/S	W/S	O/S	W/C	O/S	S/C	O/S†	S/S	- /C	O/S+C	CA+O/C

C: corn (*Zea mays* L.); CA: canola (*Brassica* species); O: oat (*Avena sativa* L.); (O): oat not harvested; R: rye (*Secale cereale* L.); S: soybean (*Glycine max* (L.) Merr.); TR: triticale (*Triticale hexaploide* Lart.); W: wheat (*Triticum aestivum* L.).

†Dolomite limestone added.

between years, a field was changed to a different class. Pearson correlation analysis was used to verify the association between the chemical features and crops. For this purposes, hierarchical values were attributed to each crop in the sequence of crops to represent the crop exigencies: soybean = 3; corn = 2; canola = 2.5; wheat, oat, rye, and triticale = 1.

RESULTS AND DISCUSSION

Comparison of NT and Forest Soils

Comparing soils collected at depths of 0.0 to 0.25 m, 0.25 to 0.5 m, and greater than 0.5 m to determine typical soil properties for an undisturbed soil from a forest area with soils from representative NT fields found increased bulk densities in the surface soils (0.0-0.5 m) in the NT fields and similar bulk densities in the greater than 0.5-m depth (Table 1). These differences are probably related to the CT that occurred before NT started in 1978. Clay content and pH were similar for the forest and NT soils. Total N that was higher in the 0.0- to 0.25-m layer in the NT soil probably relates to the surface application of fertilizer in the NT fields. Total OC was higher in the total profile in the forest soil (12.11 kg m^{-2} in the 0- to 0.5-m layers) when compared with the NT soils (8.92 and 9.82 kg m^{-2}). The lower values in the NT fields are probably related to the history of CT used in these fields, but it is particularly interesting to point out the C stock values in the upper 0- to 0.25-m layer: 6.00 kg m^{-2} under forest and 6.88 to 6.91 kg m^{-2}, respectively, under cultivation. The difference between forest and cultivation is reasonable in the second layer, where more than 3 kg C m^{-2} is observed. A first approximation argues for a conservation of the OC stock in the upper layer, but the C concentration is lower under cultivation when compared with forest, and the value of the stock is compensated by an increase in bulk density under cultivation. An average increase in OC stocks of 83 g m^{-2} year^{-1} in the 0- to 0.20-cm topsoil was measured in others oxisols (Corbeels et al., 2006). Alternative tillage and cropping systems have been shown to be a means to mitigate agricultural emissions of carbon dioxide (Paustian et al., 1997; FAO, 2001, Follet, 2001). Our results stress the need for more regional data to account for this important environmental issue of the NT systems for the 8.33 M km^2 of tropical oxisols.

Class Characterization

The mean values and confidence intervals of the soil chemical properties for the five classes averaged for the entire study period are shown in Table 3. The pH measurements had the lowest coefficient of variation (CV) between classes. Higher CV was observed for P, K, Mg, and OC. The Ca values showed low data variability within all classes. It is important to emphasize that the mean values observed for the different properties are considered (CFS, 1994) high for K contents (K > 0.45 cmol$_c$ dm^{-3}), average to low for OC in the classes I to IV

TABLE 3

Mean values and confidence intervals (95%) for the soil chemical properties by soil layers in the different classes

Class	Soil layer, m	pH	Calcium, $cmol_c\ dm^{-3}$	Magnesium, $cmol_c\ dm^{-3}$	Potassium, $cmol_c\ dm^{-3}$	OC, $g\ C\ kg^{-1}$	Extractable P, $g\ dm^{-3}$
I	0.0-0.1	5.85 ± 0.07B†	10.32 ± 0.49A	3.40 ± 0.25A	0.86 ± 0.06A	17.86 ± 0.91B	14.47 ± 1.67A
	0.1-0.2	5.64 ± 0.07b	9.84 ± 0.56a	2.70 ± 0.14a	0.65 ± 0.05b	15.77 ± 0.74bc	7.47 ± 1.12b
II	0.0-0.1	5.56 ± 0.08C	8.36 ± 0.42B	2.52 ± 0.25B	0.67 ± 0.09BC	16.35 ± 1.37B	9.93 ± 1.86B
	0.1-0.2	5.70 ± 0.09b	8.96 ± 0.64a	2.87 ± 0.32a	0.80 ± 0.09a	18.73 ± 2.19b	14.52 ± 3.00a
III	0.0-0.1	6.38 ± 0.06A	9.80 ± 0.46A	1.84 ± 0.13CD	0.69 ± 0.05B	16.72 ± 1.18B	8.10 ± 1.72B
	0.1-0.2	6.38 ± 0.07a	9.17 ± 0.52a	1.58 ± 0.10bc	0.53 ± 0.05c	14.11 ± 1.80c	4.17 ± 0.84c
IV	0.0-0.1	5.74 ± 0.06B	8.25 ± 0.25B	2.31 ± 0.17BC	0.70 ± 0.03B	16.94 ± 0.90B	8.48 ± 0.82B
	0.1-0.2	5.65 ± 0.05b	7.74 ± 0.25b	1.93 ± 0.13b	0.54 ± 0.03bc	14.15 ± 0.89c	5.10 ± 0.51bc
V	0.0-0.1	5.55 ± 0.12C	8.46 ± 0.82B	1.60 ± 0.19D	0.55 ± 0.12C	27.00 ± 3.03A	10.25 ± 2.11B
	0.1-0.2	5.40 ± 0.14c	7.58 ± 1.22b	1.41 ± 024c	0.43 ± 0.08c	27.99 ± 5.35a	6.49 ± 1.14bc
CV, %	0.0-0.1	3.43	12.38	23.60	20.39	17.27	38.00
	0.1-0.2	3.47	15.23	21.14	23.40	23.70	46.11

†Means followed by the same letter, upper case for 0.0 to 0.1 m and lower case for 0.1 to 0.2 m in the column do not differ at the 0.05 level of probability, Tukey test.

($14–20\ g\ kg^{-1}$), high for OC in class V (>$26\ g\ kg^{-1}$), high to average for P in classes I, II, and V ($9–12\ mg\ dm^{-3}$), and average to low for P in classes III and IV ($4.1–9.0\ mg\ dm^{-3}$).

The low data variability within each class is a function of the narrow range of the confidence intervals for each soil property and each depth. It also shows that the chemical similarity of the aggregated fields within the same class is an important characteristic for the description and acceptance of the proposed classification scheme. Thus, for the upper layer, the Class I had the highest mean values for Ca, Mg, K, and P. Organic C values in Class I were similar to those observed in Classes II, III, and IV. The pH values in Class I were similar to those in Class IV and lower than those in Class III. Class V included the lowest mean values for pH, Mg and K, and the highest values of OC contents at both depths. High mean values for these chemical properties are usually associated with good soil fertility, and low mean values are usually associated with poorer soil fertility. The others classes (II, III, and IV) included soil properties with intermediate mean values. These soil classes are considered to have moderate fertility (CFS, 1994). When the data of Table 3 were analyzed considering both depths, statistical differences in soil properties were not always

TABLE 4

Significant coefficient of correlation (n = 142) for a linear relationship between the soil chemical properties

Layer		Crop	pH	Ca	Mg	K	OC	P
0.0-0.1 m	Mg			0.18 $P = 0.0317$				
	K			0.35 $P < 0.0001$	0.40 $P < 0.0001$			
	OC	0.358 $P < 0.0001$						
	P			0.30 $P = 0.0003$	0.47 $P < 0.0001$	0.52 $P < 0.0001$	0.18 $P = 0.0358$	
0.1-0.2 m	Ca	0.22 $P = 0.0118$		0.78 $P < 0.0001$	0.18 $P = 0.0353$	0.28 $P = 0.0007$		0.17 $P = 0.0380$
	Mg				0.80 $P < 0.0001$	0.20 $P = 0.0146$		0.35 $P < 0.0001$
	K			0.20 $P = 0.018$	0.22 $P = 0.0092$	0.56 $P = 0.0001$		0.25 $P = 0.0023$
	OC	0.37 $P < 0.0001$						
	P	0.19 $P = 0.0241$	-0.30 $P = 0.0004$					0.33 $P < 0.0001$

found in classes close to each other, indicating that they represent transitional classes that tended to change over time. Except for Class II, the mean values of Ca, Mg, K, P, and OC decreased from the surface layer (0-0.1 m) to the second layer (0.1-0.2 m). The lower Ca and Mg contents with depth were similar to those previously observed (Muzilli, 1983; Tripplett and van Doren Jr., 1969).

The highest mean for P from the surface layer was found in Class I, differing from the other classes (Table 3). In the 0.1- to 0.2-m layer, the highest *P* values were observed in Class II. The P concentration in the surface layer of soil in NT systems is usually higher than that of the lower layer (Rhoton, 2000) and is probably caused by the annual surface application of phosphate fertilizers (Sidiras and Pavan, 1985). Soil clay particles strongly adsorb phosphate ions and limit their physical movement downward. A high correlation between extractable P and OC contents was observed only in the surface layer (Table 4), as previously observed in other environments (Ismail et al., 1994; Rhoton, 2000). The accumulation of P in the soil layers followed a similar pattern to the accumulation of the organic residues (Selles et al., 1997). This accumulation is explained by the concentration of phosphate and soluble P forms located in young crop residues on soil surface and recent dead roots (Brossard and Laurent, 1992). If adequate moisture conditions are observed, most of the residue P will be immobilized by decomposers and their predators. The new microbial water-soluble and organic P are available for the next rainfall cycle (Frossard et al, 1995), and part of these P forms can be extracted by standard physicochemical extractors.

Organic C in the five classes varied from 16.3 to 27.0 g C kg^{-1} in the 0.0- to 0.1-m layer and from 14.1 to 28.0 g C kg^{-1} in the 0.1- to 0.2-m layer. The mean OC for all fields was 17.4 g C kg^{-1} in the surface layer. This value was less than the mean content observed under the forest (Table 1) and even lower than the mean value for other soil reference profiles (mean, 21.0; n = 6) in the same region (EMBRAPA, 1984). Muzilli (2002) reported an average of 15.0 to 20.0 g C kg^{-1} for OC in NT soils derived from basalt. The two layers in class V have a significantly higher OC content than the others classes, but also the highest confidence intervals. Class V is only differentiated for the year 1991 (Fig. 1) after two cycles of soybean for all the fields (Table 2). The highest and the lowest OC mean contents were observed in 1984 and 1991, respectively. The highest mean was found in field 7 (18.9 g C kg^{-1}) and the lowest in field 2 (15.4 g C kg^{-1}). A significant positive correlation ($P < 0.0001$) between the sequence of crops and OC contents in both layers was observed (Table 4). Thus, the type of crop in the cropping sequence explains the variability of OC observed, and the significant correlation observed stressed their role for the maintenance of OC. These results agree with Corbeels et al. (2006), who demonstrated that direct seeding mulch-based cropping stores C in oxisols that were previously depleted as a result of several years of CT soybean monoculture. The processes are the high water-soluble C inputs to soil from crop residues (Metay et al., 2007) and the decrease in N outputs from the plant-soil system, which favors decomposition and integration of OM to soil.

Classification Changes Caused by Time

In NT systems, conservation of soil OC, remobilization and redistribution of nutrients by crops, and maintenance of the nutrient bioavailability are expected (Oliveira and Pavan, 1996). The variations of pH and nutrients are presented in Fig. 2. For the 10-year monitoring, the mean values are pH = 5.8 ± 0.3, P = 10.3 ± 4.6 g dm^{-3}, $\sum$cations = 12.3 ± 1.9 cmolc dm^{-3}. The relative stability for the entire study period indicated a relative stability of the system, but the yearly fluctuations showed a strict dependence of the sustainability of the system to the crop sequences planted by the farmer.

The changing classification of the different fields with time represents the transition of the chemical properties over time, which is useful for monitoring the effects of crop sequences.

The field classes (Fig. 1) show the annual changes of the soil chemical properties over the study period. Three periods were identified: the first from 1983 to 1984, with Class III dominant (red); the second period from 1986 to 1990, with Class IV (green) dominant; and the third period from 1992 to 1994, with Class IV (green) to II (orange) to I (yellow) dominating.

The first important change in the soil chemical properties took place in 1985 with the availability of nutrients increasing causing a change from Class III to I. This change is associated with the application of lime in

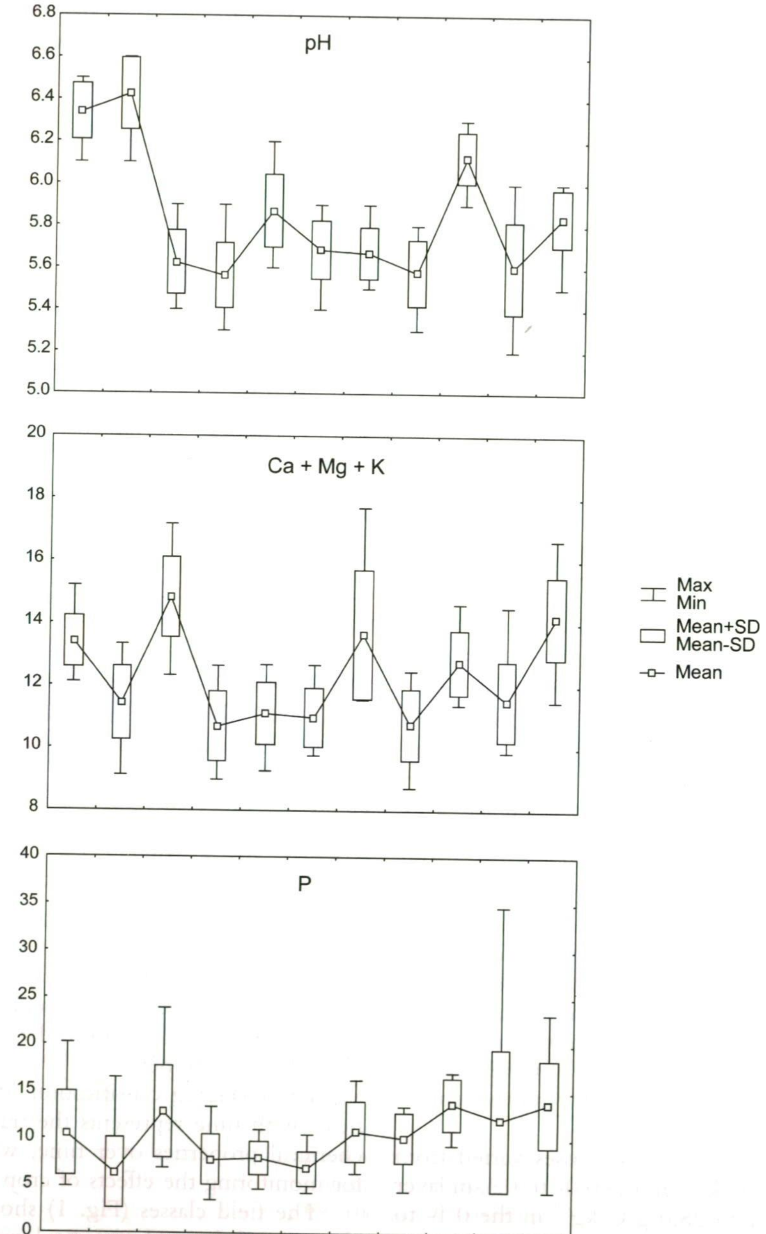

Fig. 2. Nutrients ($\sum$cations $cmol_c\ dm^{-3}$ and P g dm^{-3}) and pH time variations in the soil surface layers.

February 1985. In addition, oats sowed in 1985 were used as green manure (Table 2). In this soil, the dolomitic lime is the source of Ca and Mg. In Class III, the mean pH was 6.38, which is too high for an active dissolution of the carbonates. The oat crop as green manure had a dissolution effect and a remobilization of the elements, as was observed with Ca remaining constant and Mg increasing from Class III to Class I. In addition, the green manure maintained the OC, and as expected, the oat residues contributed to providing additional extractable K and P (Santos et al., 1995). These changes are supported by the positive correlation between crops and OC observed in the two soil layers (Table 4).

The second important change was observed in 1991. In 1990, five fields were in Class I, two in Class II, and the rest in Class IV (green). In

1991, 12 fields were observed in Class V (blue). The change to Class V stressed the decrease of Mg and K, and a lower mean pH value. Between 1986 and 1991, soybeans represented half of the crops planted in the summer season. The farmer, aware of this excess of soybean crops, added lime in 1990 and an oat crop in the last period of 1991. Class V was observed in the area after a monoculture succession of soybeans (Table 2), this crop did not affect the results as it was observed in 1985. But by the last period from 1993 to 1994, which is characterized by greater crop diversification, many fields returned to Classes II and I.

These transitions between classes during the study period demonstrate the importance of good management (i.e., lime, cropping sequence) for maintaining good chemical properties under NT management. Fertilizations carried out during this period, associated with the new liming application in 1990, were sufficient to replace the nutrients removed by harvesting.

CONCLUSIONS

The rapid expansion of NT and minimum tillage systems replacing CT management systems in Brazil indicates that it is an economically acceptable management system for subtropical areas. However, there is a need of information about soil fertility at the farmer's level. We used a set of data provided by a farmer on 16 fields with a history of NT management for a 10-year period to investigate how no-till impacted six basic fertility soil chemical determinations. Classification of the fields related to the mean values of different soil chemical properties showed changes in field classification related to management practice (lime addition, cropping sequence). Organic C in the NT soils was affected, particularly in the surface layer, mainly by the cropping sequence, demonstrating the importance of the crop patterns in maintaining soil organic matter. This long-term study, which monitored soil chemical properties under NT management over a 10-year period, shows that it is possible to maintain good soil chemical properties under NT management under subtropical conditions. But the results stressed that short-term and long-term culture rotation, including soybean, wheat, corn, and oatmeal, needs corrections via liming and a rigorous fertilizer strategy.

ACKNOWLEDGMENT

The authors thank Mr Carlos Abudi who allowed us to study his farm during this research.

REFERENCES

Bayer, C., J. Mielniczuk, L. Amado, L. Martin-Neto, and S. V. Fernandes. 2000. Organic matter storage in a sandy clay loam acrisol affected by tillage and cropping system in southern Brazil. Soil Tillage Res. 54:101–109.

Blevins, R. L., G. W. Thomas, and P. L. Cornelius. 1977. Influence of no-tillage and nitrogen fertilization on certain soil properties after 5 years of continuous corn. Agron. J. 69:383–386.

Brossard, M., and J. Y. Laurent. 1992. Le phosphore dans les vertisols de la Martinique (Petites Antilles). Relations avec la matière organique. Cah. ORSTOM sér. Pédol. 27:109–119.

Cannel, R. Q., and J. R. Finney. 1973. Effects of direct drilling and reduced cultivation on soil conditions for root growth. Outlook Agric. 7:184–189.

Castro Filho, C., A. Lourenço, M. F. Guimarães, and I. C. B. Fonseca. 2002. Aggregate stability under different soil management systems in a red latosol in the state of Parana, Brazil. Soil Tillage Res. 65:45–51.

Castro Filho, C., O. Muzilli, and I. Podanosch. 1998. Estabilidade dos agregados e sua relação com o teor de carbono orgânico num Latossolo Roxo distrófico, em função de sistemas de plantio, rotações de cultura e métodos de preparo das amostras. Rev. Bras. Ci. Solo 22:527–538.

CFS (Comissão de Fertilidade do solo RS/SC), 1994. Recomendações de adubação e de calagem para os estados do Rio Grande do Sul e Santa Catarina. 3. ed. SBCS-Núcleo Regional, Passo Fundo, Brasil.

CISIA - CERESTA, 1998. SPAD for Windows (software). v 3.5, 1998.

Corbeels, M., E. Scopel, A. Cardoso, M. Bernoux, J. M. Douzet, and M. S. Neto. 2006. Soil carbon storage potential of direct seeding mulch-based cropping systems in the Cerrados of Brazil. Glob. Chang. Biol. 12:1773–1787.

EMBRAPA (Empresa Brasileira de Pesquisa Agropecuária), Serviço Nacional de Levantamento e Conservação de Solos, 1984. Levantamento de Reconhecimento dos Solos do Estado do Paraná. Tomo I. Boletim Técnico, 57. Rio de Janeiro, Brasil.

EMBRAPA (Empresa Brasileira de Pesquisa Agropecuária), Centro Nacional de Pesquisa de Solos (CNPS), 1997. Manual de métodos de análise de solo. 2a edição revista e atualizada. EMBRAPA-CNPS, Rio de Janeiro, Brasil.

EMBRAPA (Empresa Brasileira de Pesquisa Agropecuária), Centro Nacional de Pesquisa de Solos (CNPS), 1999. Sistema Brasileiro de Classificação de Solos. Serviço de Produção de Informação (SPI), Brasília, Brasil.

Ernani, P. R., C. Bayer, and L. Maestri. 2002. Corn yield as affected by liming and tillage system on an acid Brazilian Oxisol. Agron. J. 94:305–309.

Ismail, I., R. L. Blevins, and W. W. Frye. 1994. Long-term no-tillage effects on soil properties and continuous corn yields. Soil Sci. Soc. Am. J. 58:193–198.

FAO, 2001. Soil carbon sequestration for improved land management. World Soil Resources Report 96, Rome.

Follet, R. F. 2001. Soil management concepts and carbon sequestration in cropland soils. Soil Tillage Res. 61:77–92.

Frossard, E., M. Brossard, M. Hedley, and A. Metherell. 1995. Reactions controlling the cycling of P in soils. *In:* Phosphorus in the Global Environment. H. Tiessen (ed.). SCOPE, John Wiley & Sons, Chichester, pp. 107–137.

Leite, L. F. C., E. S. Mendonça, P. L. O. A. Machado, E. I. Fernandes Filho, and J. L. C. Neves. 2004. Simulating trends in soil organic carbon of an Acrisol under no-tillage and disc-plow systems using the Century model. Geoderma 120:283–295.

Mascarenhas, H. A. A., R. Hiroce, N. R. Baraga, M. A. C. Miranda, C. V. Pommer, and E. Sawazaki. 1978. Efeito do nitrogênio residual de soja na produção de milho. *In:* EMBRAPA/CNPSoja, Seminário Nacional de Pesquisa de Soja. Anais, Londrina, Brasil, pp. 301–318.

Metay, A., J. A. A. Moreira, M. Bernoux, T. Boyer, J. M. Douzet, B. Feigl, C. Feller, F. Maraux, R. Oliver, and E. Scopel. 2007. Storage and forms of organic carbon in a no-tillage under cover crops system on clayey Oxisol in dryland rice production (Cerrados, Brazil). Soil Tillage Res. 94:122–132.

Muzilli, O. 1983. Influência do sistema de plantio direto, comparado ao convencional, sobre a fertilidade da camada arável do solo. Rev. Bras. Ci. Solo. 7:95–102.

Muzilli, O. 1985. Fertilidade do solo em plantio direto. *In:* Atualização em plantio direto. A. L. Fancelli, and P. V. Torrado, P. V. (eds.). Fundação Cargill, Campinas, Brasil, pp. 147–160.

Muzilli, O. 2002. Manejo da matéria orgânica no sistema de plantio direto: a experiência do Estado do Paraná. Piracicaba. POTAFOS. Informações Agronômicas 100:6–10.

Oliveira, E. L., and M. A. Pavan. 1996. Control of soil acidity in no-tillage system for soybean production. Soil Tillage Res. 38:47–57.

Paustian, K., H. P. Collins, and E. A. Paul. 1997. Management controls on soil carbon. *In:* Soil Organic Matter in Temperate Agroecosystems. E. A. Paul, K. Paustian, E. T. Elliott, and C. V. Cole (eds.). CRC Press, Boca Raton, FL, pp. 15–49.

Phillips, R. E., R. L. Blevins, G. W. Thomas, W. W. Frye, and S. H. Phillips. 1980. No-tillage agriculture. Science 208:1108–1113.

Rhoton, F. E. 2000. Influence of time on soil response to no-till practices. Soil Sci. Soc. Am. J. 64:700–709.

Roth, C. H., C. Castro Filho, and G. B. Medeiros. 1991. Análise de fatores físicos e químicos relacionados com a agregação de um Latossolo Roxo distrófico. Rev. Bras. Ci. Solo 15:241–248.

Santos, H. P., G. O. Tomm, and J. C. B. Lhamby. 1995. Plantio direto versus convencional: efeito na fertilidade do solo e no rendimento de grãos de culturas em rotação com cevada. Rev. Bras. Ci. Solo 19:449–454.

Selles, F., R. A. Kochhann, J. E. Denardin, R. P. Zentner, and A. Faganello. 1997. Distribution of phosphorus fractions in a Brazilian Oxizol under different tillage systems. Soil Tillage Res. 44:23–34.

Sidiras, N., and M. A. Pavan. 1985. Influência do sistema de manejo do solo no seu nível de fertilidade, Campinas. Rev. Bras. Ci. Solo 9:249–254.

Silveira, A. M., R. L. Victoria, M. V. Ballester, P. B. Camargo, L. A. Martenelli, and M. C. Piccolo. 2000. Simulação dos efeitos das mudanças do uso da terra na dinâmica de carbono no solo na Bacia do Rio Piracicaba. Pesq. Agrop. Bras. 25.389–399.

Stocking, M. A. 2003. Tropical soils and food security: the next 50 years. Sci. 302:1356–1359.

Tripplett Jr, G. B., and D. M. van Doren Jr. 1969. Nitrogen, phosphorus and potassium fertilization of non-tillage maize. Agron. J. 61:637–639.